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HARP 5-INCH AND 16-INCH GUNS AT YUMA PROVING GROUND, ARIZONA

by

C. H. Murphy
G. V. Bull

February 1967

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U. S. ARMY MATERIEL COMMAND
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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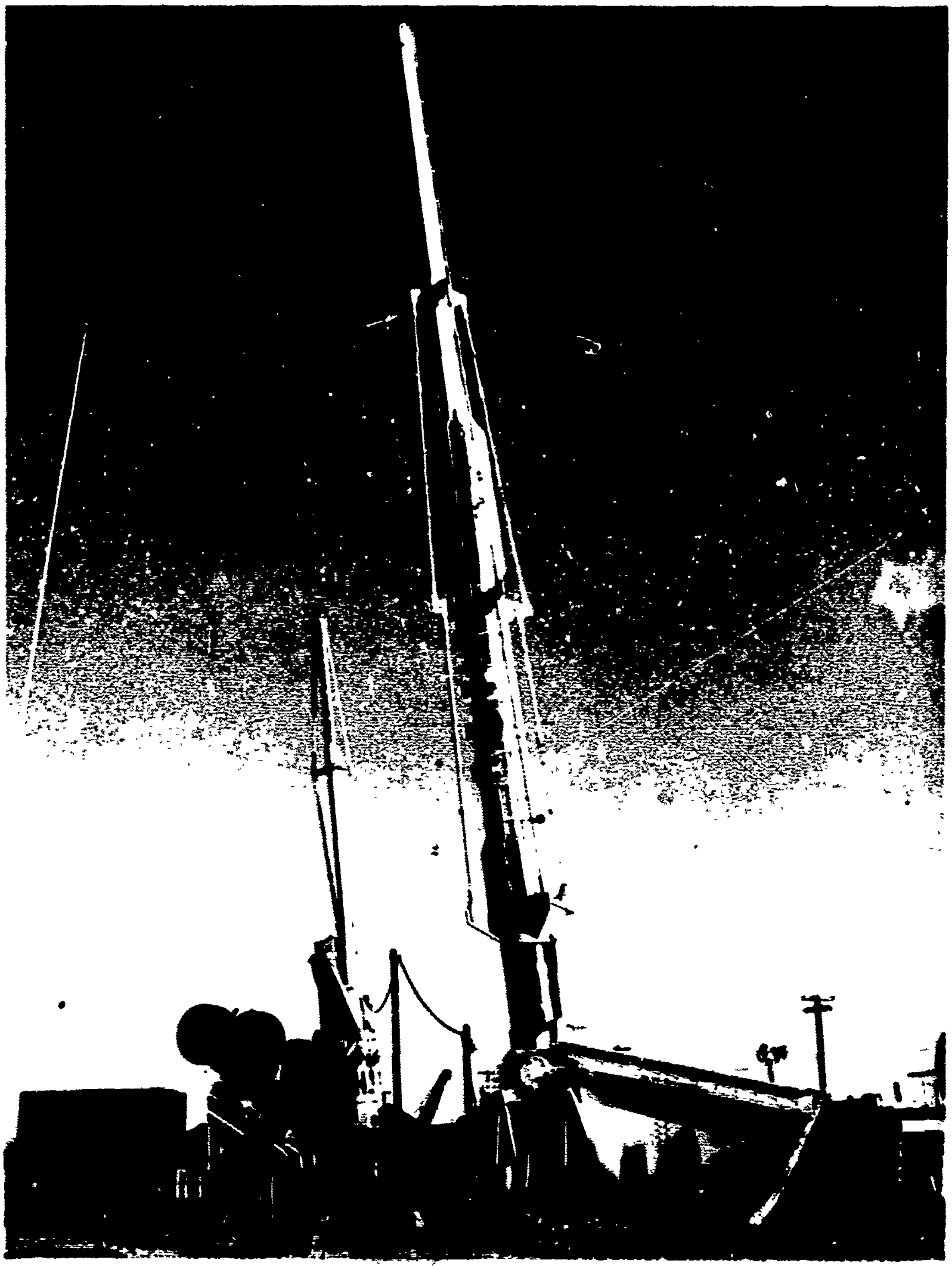
RDT&E Project No. 1V025001A616

ABERDEEN PROVING GROUND, MARYLAND



Frontispiece YPG 5- and 16-inch guns

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

MEMORANDUM REPORT NO. 1825

CHMurphy/GVBull/cr
Aberdeen Proving Ground, Md.
February 1967

HARP 5-INCH AND 16-INCH GUNS AT YUMA PROVING GROUND, ARIZONA

ABSTRACT

The 5- and 16-inch guns at Yuma Proving Ground and their associated instrumentation and flight results for 1966 are described in detail. The introduction of multi-point ignition for the 16-inch gun produced a record altitude of 111 miles using special propellants and the moderate altitude of 77 miles with surplus Naval propellant. Twenty-four ionospheric wind profiles have been obtained from 16-inch gun firings and 15 stratospheric profiles from the 5-inch firings. Telemetry performance and ground recovery capability have been demonstrated.

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1. INTRODUCTION

Project HARP is devoted toward the development of high altitude gun-launched rockets and projectiles and the acquisition of engineering and scientific data on the upper atmosphere and the vehicle-environment interactions. As part of this effort, 5-inch guns have placed 25-pound projectiles at 250,000 feet, 7-inch guns have placed 60-pound projectiles at 330,000 feet and 16-inch guns have reached 590,000 feet with 185-pound projectiles. Chaff, aluminized parachutes and chemicals to produce luminous trails have been released to measure winds from 100,000 feet to 590,000 feet, and on-board telemetry units with temperature and electron density sensors are in an advanced state of development (A-20).* Gun-boosted rockets are under development for the 7- and 16-inch guns (B-11) and an attitude control system is under development for the 16-inch gun boosted rocket (D-3).

Until late 1966, the primary development firings of the 5- and 7-inch systems were made at Wallops Island, Virginia, and the only vertical fire 16-inch gun was located on the West Indian island of Barbados. Since these ranges involved water impacts, recovery of developmental payloads was very difficult if at all possible. This was a severe limitation on development of telemetry, antennas, various sensors, and the attitude control unit. Early in 1965, it was decided that a second 16-inch gun vertical fire installation should be established at a land impact range. In view of the presence of a standard Mark 7 sixteen-inch Naval rifle and mount at Yuma Proving Ground (YPG), Arizona, a request for authorization for gun modification and horizontal firing capability was made to the U.S. Army Test and Evaluation Command (TEC). Approval was received on 11 March 1965 with an assigned project number, 9-5-0035-01. On 24 November 1965, approval for vertical firings under project number

An extensive bibliography of HARP publications is provided at the end of this report. A letter and number in parentheses identify a particular item in this bibliography.

5-5-9915-04 was received and in August 1966 the placement of a vertical fire 5-inch gun next to the 16-inch gun was authorized. The excellent visibility at YPG which is quite valuable for optical measurements of the upper atmosphere became a side benefit and a scientific sounding program was also planned.

The 16-inch gun of the HARP program has been a joint technical endeavor of McGill University's Space Research Institute (SRI) and the U.S. Army's Ballistic Research Laboratories (BRL) with the primary engineering and operational responsibility resting with the SRI. This effort was initiated with funding from the Army Research Office in 1962 and was an Army funded program until June 1964. At that time, a three year joint funding was set up between the U.S. Army and the Canadian Department of Defence Production. The establishment of a second 16-inch gun at an Army Proving Ground was not of interest to the Canadian government, although specific tests at this Army installation were felt to be appropriate to the jointly funded program. At the third meeting of the joint U.S.-Canada Steering Committee for Project HARP-McGill held on 8 July 1965, the Space Research Institute was authorized to carry out the necessary modifications to the Yuma gun with the restriction that all additional funds would be supplied by the U.S. Army.

In September 1965, work on the Yuma gun commenced with the arrival of an SRI resident engineer, Mr. Roy Kelly. The rifled barrel was pulled and the mount modified for vertical fire. A second* Mark 7 barrel was obtained from the Navy at Pocatello, Idaho, and smoothbored there. A 51-foot barrel piece was obtained and smoothbored for a muzzle extension. The 140-ton barrel and 30-ton extension were then moved by rail to Yuma and overland to the YPG gun site where they were assembled in the gun mount and welded together. An additional 15 tons of stiffening

Since movement of the Yuma rifled barrel to Pocatello would cost over $10,000, this barrel was laid beside its mount.

members and tie rods were welded to the extended tube. Finally, a specially built 11-inch diameter, 20-foot long elevation cylinder was emplaced and the installation was ready for vertical fire on 7 June 1966.

In this report, the two HARP guns at Yuma and their associated radar, ionosonde and K-46 camera sites will be described and a complete resume given of the 1966 firing results for these guns.

It should be noted that the 16-inch guns at Barbados and Yuma are in no way competitive. Scientific soundings which can be made at both facilities provide data for two different latitudes (13.1°N for Barbados and 32.9°N for Yuma). The Yuma range area, 40 x 10 miles, limits firings to unpowered flights of completely developed projectiles but provides the essential capability of ground recovery. The ability of the Barbados gun to fire over water far into the South Atlantic allows for long range gun-boosted rocket flights as well as developmental flights of rockets and projectiles.

2. HARP FACILITIES AT YUMA PROVING GROUND

Yuma Proving Ground is located in the Sonoran desert in the southwest corner of Arizona and is bounded on the west by the Colorado River. It is 40 miles from the Mexican border, about 185 miles inland from San Diego, California, and about the same distance westward from Phoenix, Arizona. The HARP guns are located at Gun Position 10 on the KOFA Range Area which extends eastward from Arizona State Highway 95 for about 40 miles. The locations of the 16-inch gun and the special HARP instrumentation are given in Table I. In addition to these, both a fixed and a mobile 250 MHz TM receiving station operated by YPG have supported HARP firings.

2.1 Guns and Projectiles

The 16-inch gun is 119 feet 4.7 inches long and fires on a nominal azimuth of 78.2°. Its loader-rammer system was designed by Rock Island Arsenal (C-18) and consists of two wheeled-vehicles. The projectile is first placed in the loading tray on the first vehicle (Figure 1) and the

Table I. Location of HARP Equipment

	Latitude	Longitude	Elevation (meters)
16-inch gun	32° 52' 33.2"	114° 19' 31.7"	141.9
MPS-19 radar	32° 52' 26.7"	114° 20' 8.3"	
Ionosonde	32° 56' 3.8"	114° 10' 34.4"	
K-46 Cameras			
AWC, Yuma	32° 41' 15.6"	114° 29' 29.9"	67.6
Blythe, Cal.	33° 36' 27.1"	114° 35' 29.7"	81.7
Gila Bend, Ariz.	32° 56' 42.6"	112° 43' 50.5"	221.0

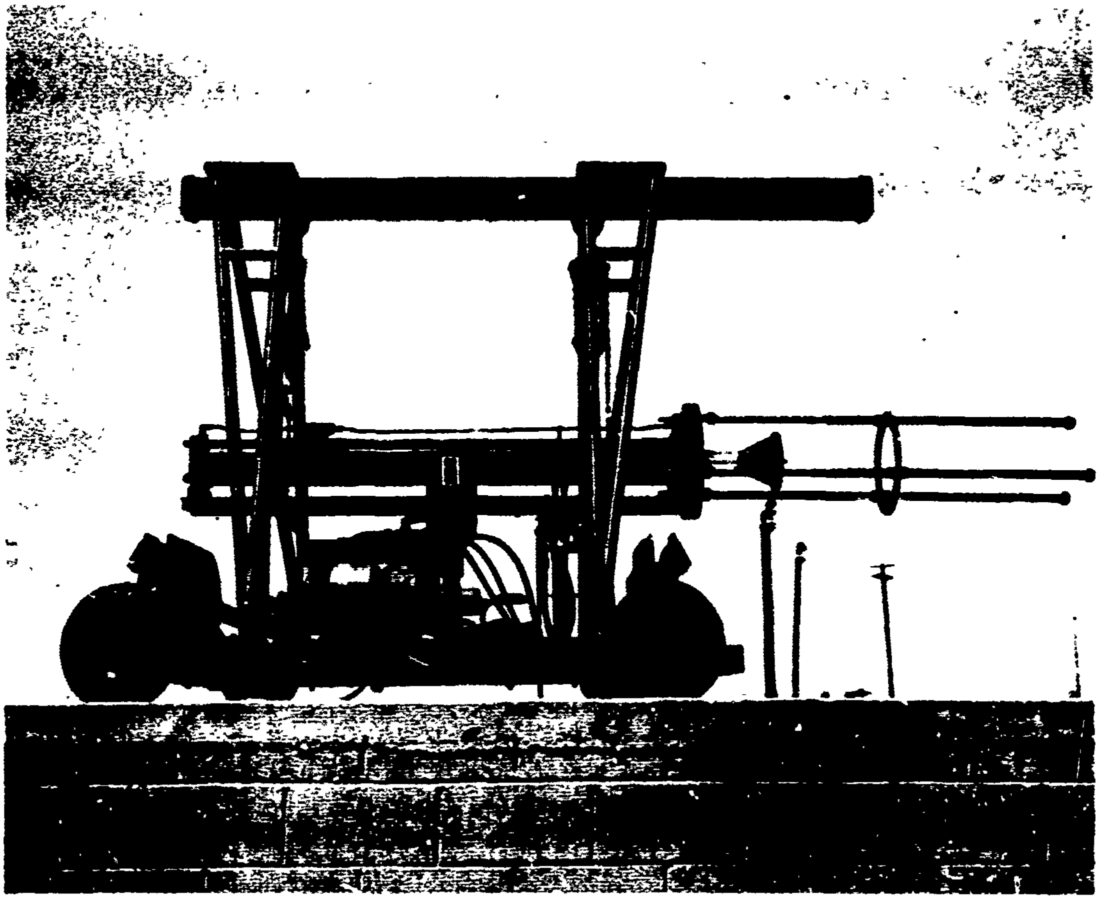


Figure 1. Loading tray with vehicle

tray is then inserted in the breech. After this vehicle is rolled aside, the second vehicle carrying a hydraulic cylinder (Figure 2) is rolled forward, attached to the breech and the projectile with its sabot is rammed forward, with a maximum force of 50 tons, to its seating position.

The gun tube was smoothbored to a diameter of 16.40 inches and the 18.35 inch diameter 70.1 inch long chamber and 10.4 inch long transition section lengthened 83.8 inches with a 16.9 inch diameter section (Figure 3). Six 1/4 inch holes were drilled one, three and five feet from the muzzle on the south side and two, four, and six feet from the muzzle on the north side. Electrical contacts placed in these holes are used to record time of passage of the projectile and thereby form a muzzle velocity measurement system (A-19). The muzzle is sealed before firing by a Mylar sheet and the bore is evacuated to one-tenth atmosphere to yield an estimated velocity increment of 150 feet per second.

The 5-inch extended smoothbore gun is located on a steel ramp 20 feet south of the 16-inch gun. It is 33 feet long, made from two 120 mm T-123 barrels, and placed in a 155 mm mobile mount. This gun is loaded by a small hydraulic cylinder with a 10-ton maximum force.

The basic 16-inch glide projectile is the Martlet 2C which has a flight weight of 185 pounds and is held in the gun by a base pusher sabot weighing 230 pounds (Figure 4). The HARP 5.1 five-inch projectile has a flight weight of 20-23 pounds and is supported in its gun by a more sophisticated center sabot weighing 5 pounds (Figure 5). Both sabots separate from their projectiles shortly after launch and fall within a 1/2 mile circle about their guns. The achieved performance of these missiles is given in Figure 6.

2.2 Radar and Launch Control

Three thousand two hundred feet behind the gun position are located vans of a mobile MPS-19 radar set in a T formation and connected by a small frame launch control office (Figure 7). From this point, radio, telephone or intercom communication is available to the YPG control

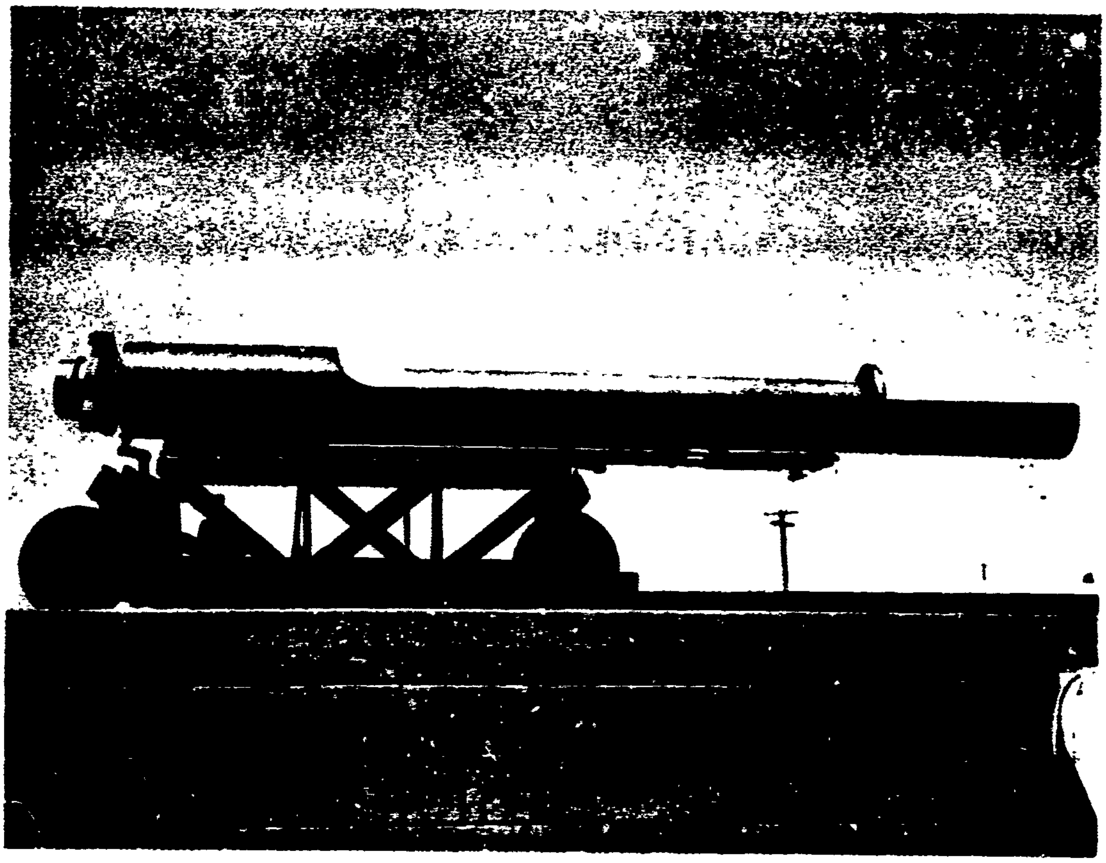
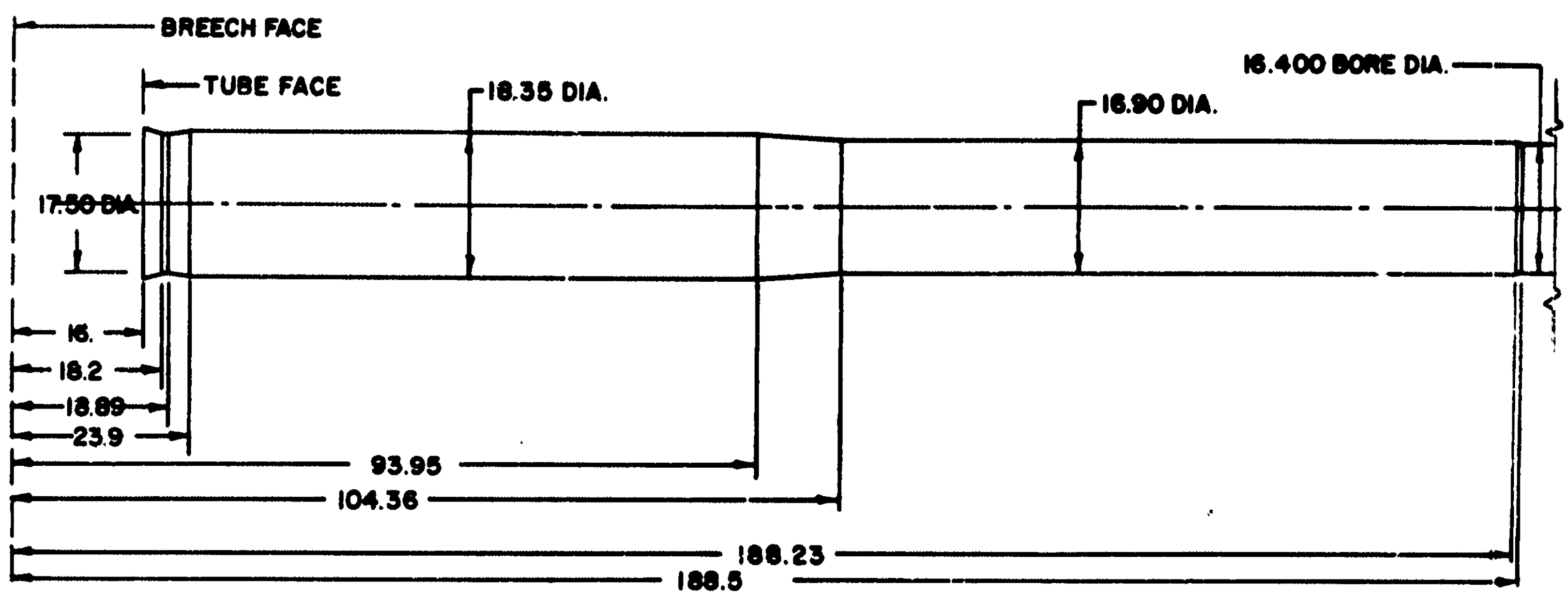


Figure 2. Rammer with vehicle

CHAMBER OF 16-INCH YPG GUN



TOTAL LENGTH OF GUN FROM BREECH FACE TO MUZZLE IS 119 FT. 4 INS.

Figure 3. 16-inch gun chamber

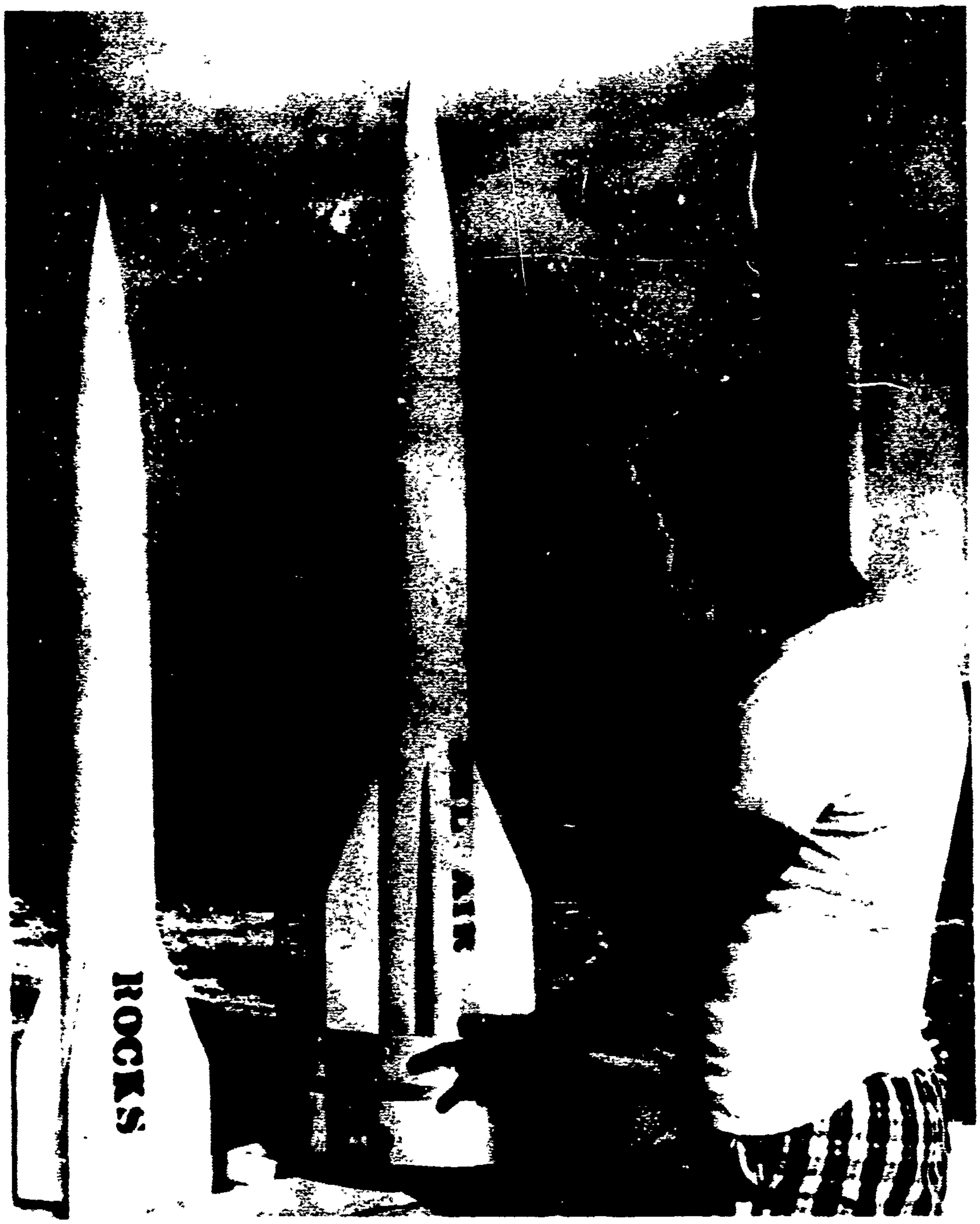
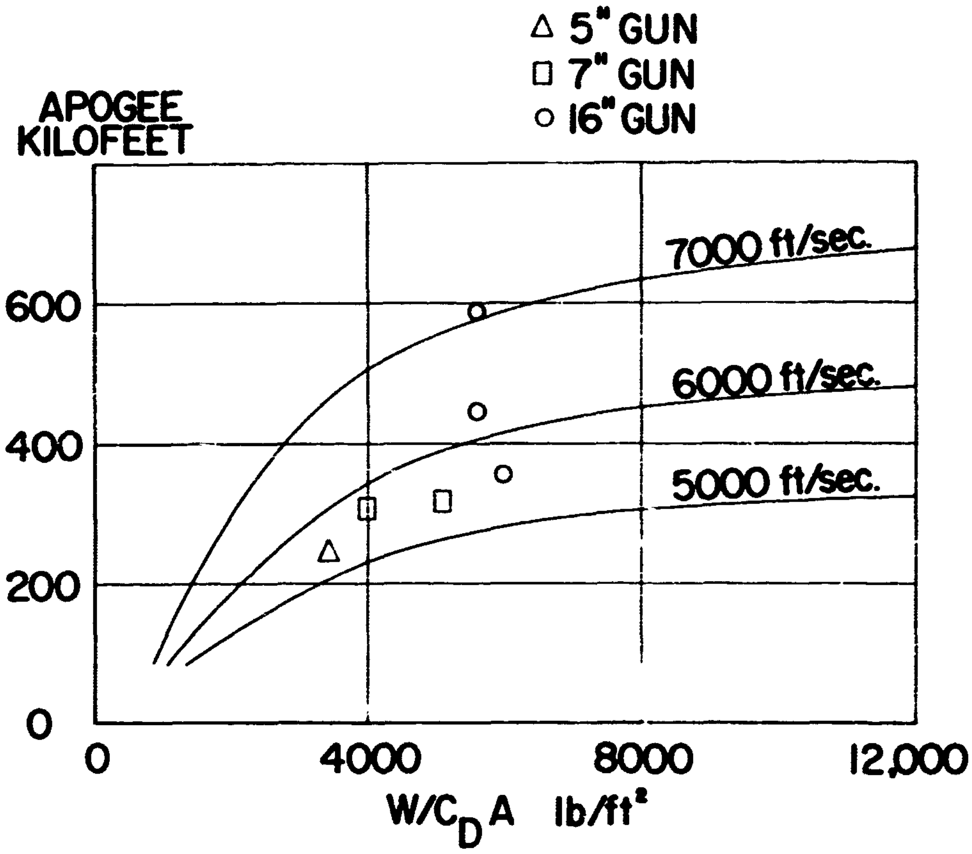


Figure 4. Martlet 2C's with and without sabot

Figure 5. HARP 5.1 five-inch projectile with center sabot

GLIDE VEHICLES



5" GUN	5400 ft/sec.	250 kft	23 lb.
7" GUN	5400 ft/sec.	300 kft	59 lb.
7" GUN	5900 ft/sec.	330 kft	27 lb.
16" GUN	5600 ft/sec.	350 kft	185 lb.
16" GUN	6300 ft/sec.	465 kft	185 lb.
16" GUN	7100 ft/sec.	590 kft	185 lb.

Figure 6. Apogee for HARP glide vehicles

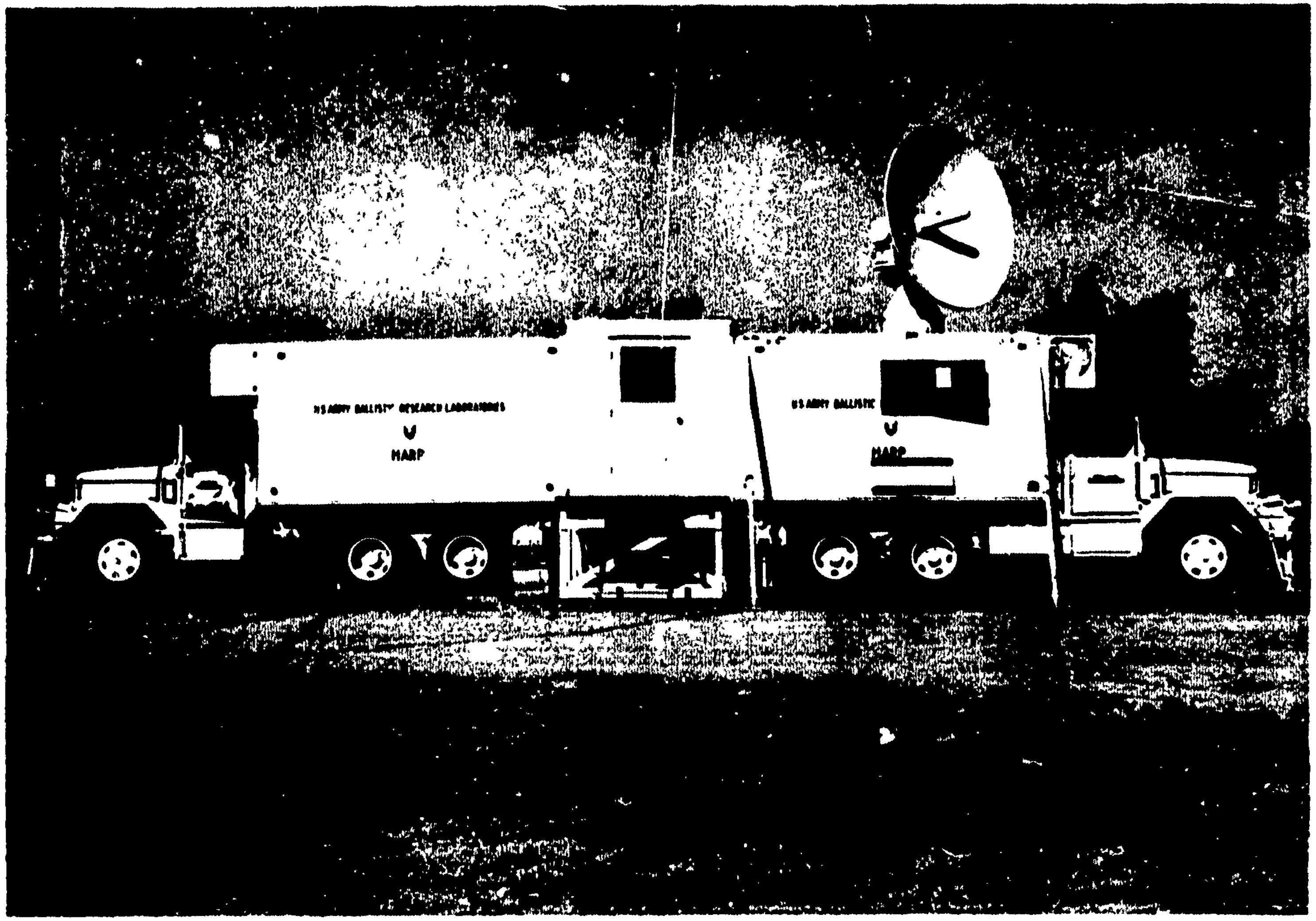


Figure 7. MPS-19 radar and HARP launch control

tower and other YPG downrange points, the ionosonde, the K-46 camera sites, TM receiver stations, when necessary, and the firing circuit located in a trailer near by. This radar is identical to that located at the HARP Barbados range and can skin track Martlet 2C projectiles up to 350,000 feet. On six occasions, this radar was able to reacquire Martlet 2C's on their down legs and furnish impact locations and time. The 5-inch projectiles can be skin-tracked to 200,000 feet. Their aluminized parachutes can be acquired immediately after ejection and then tracked for wind profiles or ground recovery.

2.3 K-46 Camera Stations

The primary scientific experiment performed at YPG during 1966 involved the creation of luminous trails by ejection of tri-methyl-aluminum (TMA) and the measurement of photographic records of these trails to obtain wind profiles in the altitude range of 90-180 km. The basic ground instrumentation of the three K-24 camera sites at Yuma, Gila Bend and Blythe were designed, built and operated under BRL contract by Space Instruments Research, Inc. of Atlanta, Georgia. Each station consists of two K-46 cameras mounted on a pedestal and an associated battery-operated control unit (Figure 8). During each 30 second cycle of operation, the cameras take pictures with 3, 6, and 9 second exposures and each frame of film is marked with time of exposure, number of shot and site location in binary code. All sites are in constant telephone communication with Launch Control through a conference call hookup.

2.4 Ionosonde and Spaced Receivers

On the north side of 25th Street near tower 18.1 about 8.7 miles east and 4.2 miles north of the 16-inch gun is located a trailer-mounted C-4 ionosonde and a 60-foot antenna tower (Figure 9). This instrument is operated by personnel from ESSA's Institute for Telecommunication Sciences and Aeronomy at Boulder, Colorado during firing series and provides measurements of the Sporadic E layer for theoretical correlation with the measured ionospheric winds (D-6). On the south side of the road,

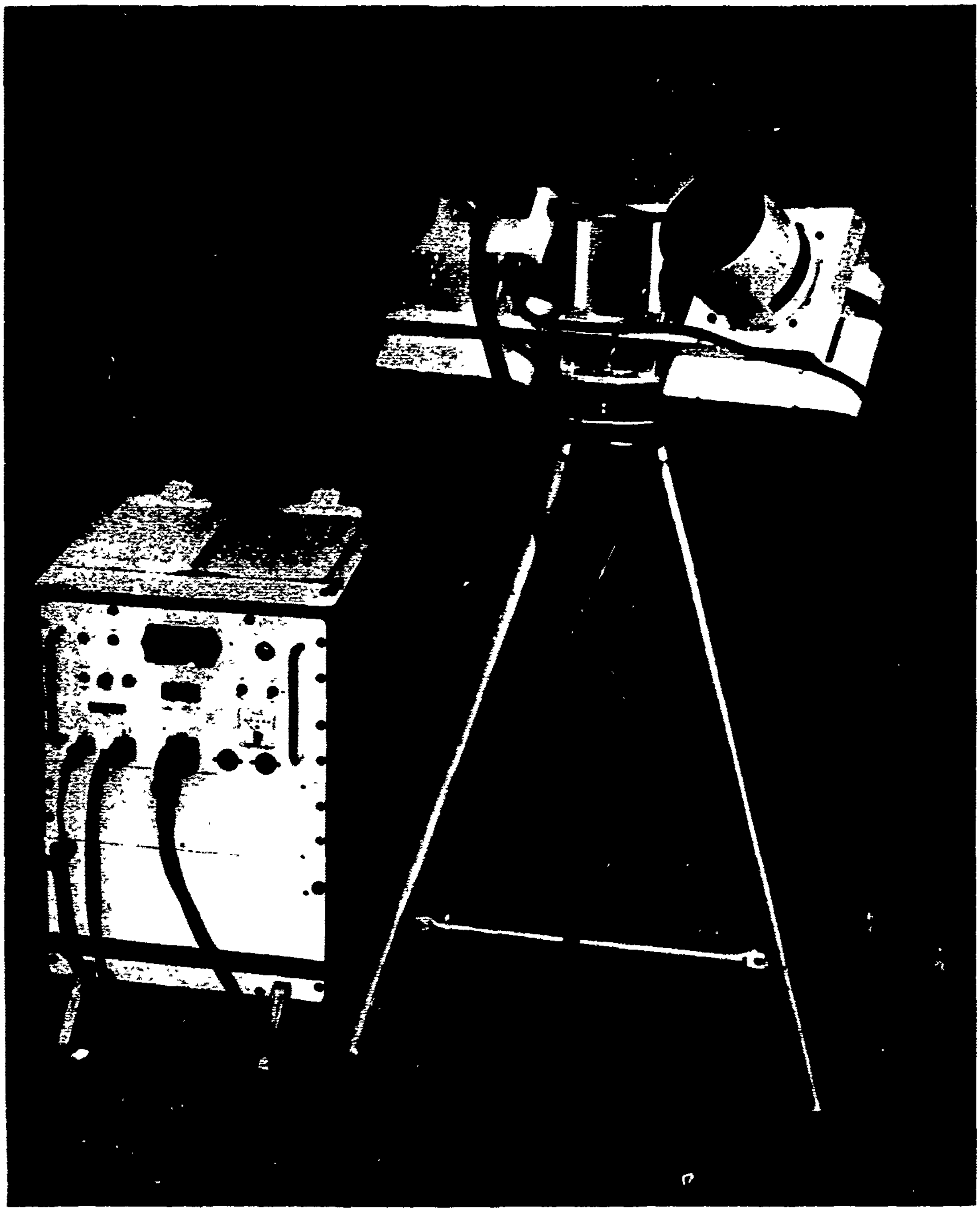


Figure 8. K-46 cameras and control unit

Figure 9. ESSA ionosonde and antenna tower

four antennas are located for spaced receiver measurements of drift of particular groups of electrons. These measurements were first taken in November 1966, and an analysis of the electron cloud velocity and a comparison with the neutral wind is now in progress.

3. SIXTEEN-INCH GUN FIRINGS-JUNE TO NOVEMBER 1966

During 1966, three firing series of the 16-inch gun were conducted. In June, an initial series of three wooden slugs and six TMA-carrying Martlet 2C's was fired to verify the gun condition and the operational capability of the supporting instrumentation. The October series of six TMA-Martlet 2C's and one Lahive (Low Altitude High Velocity) 15° cone with TM was primarily devoted to engineering tests of the new multiple-point ignition system of the powder charges and the performance of the Lahive cone's telemetry unit, while the November series of 17 TMA-Martlet 2C's was an intensive scientific probing of the lower ionosphere during the spectacular Leonide meteorite shower of 1966. Gun performance and dispersion data are summarized in Table II.

3.1 Interior Ballistics

Before the Yuma firings, the major improvement in gun performance occurred when the 51-foot muzzle extension was added to the Barbados gun, thereby increasing the muzzle velocity for Martlet 2C's from 5600 feet per second to 6300 feet per second and the peak apogee from 350,000 feet to 465,000 feet. The Barbados performance* for WM/M .225 web and M8M .220 web is summarized in Table III. Ignition was by a single primer in the breech block.

During 1965, a step in the pressure rise for the breech pressure-time records was regularly observed. Since charge lengths as short as 130 inches in the 190 inch long chamber were used, it was believed that

**WM/M is a multi-perforated British propellant (WM) and M8M is a modified M8 propellant which was pressed dry rather than formed through the use of a solvent.*

Table II. Sixteen-Inch Firings at YPG-1966

a) Gun Performance

Date	Local Time MST	Rd[1] No.	Powder	Wt Lb	Pressure Kilo-lb/in[2] M 11	Gage[3]	Muzzle Vel Ft/Sec	Apogee Kilofeet
June 7	1818	001(W)	NAVY	700	13.0	---	3360[4]	No track
8	1927	002(W)	NAVY	800	14.4	14.1S	3190[4]	No track
13	1228	003(W)	WMM	660	21.3	20.6S	4810[4]	No track
13	2025	004	WMM	760	40.0	---	5930	415
13	2215	005	WMM	780	33.2	31.9S	5810	398
14	2146	006	WMM	780	44.0	42.7S	6060	400
14	2317	007	WMM	800	51.4	50.0S	6270	Damaged
15	0127	008	WMM	760	29.8	30.0T	5630	375
15	0305	009	WMM	780	34.6	33.0T	5850	410
Oct 25	2159	010	NAVY(M*)	1095	34.9	---	5250	310
26	2055	011	NAVY(M*)	1225	50.3	43.5K	5950	410
26	2356	012	WMM(M)	920	54.4	47.0K	6800	540
27	1547	013(L)	WMM(M)	900	45.6	---	7100	No track
27	1952	014	NAVY(M*)	1275	51.7	44.0K	5900	415
27	2146	015	WMM(M)	920	53.5	46.0K	6780	535
27	2320	016	WMM(M)	950	60.0	54.0K	7040	Damaged
Nov 16	1841	017	NAVY(M*)	1290	47.7	---	5900[4]	396[6]
16	2041	018	NAVY(M*)	1292	56.4	49.4K	5900[4]	395

Table II. Sixteen-Inch Firings at YPG-1966 (Continued)

a) Gun Performance

Date	Local Time MST	Rd[1] No.	Powder[2]	Wt Lb	Pressure Kilo-lb/in² M11	Pressure Kilo-lb/in² Gage[3]	Muzzle Vel Ft/Sec	Apogee Kilofeet
Nov 16	2231	019	NAVY(M*)	1296	48.5	49.5K	5850[4]	375
17	0015	020	NAVY(M*)	1296	47.5	45.0K	5950[5]	415
17	0316	021	NAVY(M*)	1290	60.8	---	---	Damaged
18	1820	022	NAVY(M*)	1263	49.3	---	5900	400
18	2012	023	NAVY(M*)	1263	53.9	48.8K	5850	410
18	2149	024	WMM(M)	922	51.0	46.3K	6650	510
18	2342	025	M8M(M)	880	44.0	38.7K	6400[5]	490
19	0100	026	M8M(M)	910	46.7	40.6K	6650[5]	530
19	0234	027	NAVY(M*)	1270	45.9	42.5K	5850[5]	400
19	0451	028	M8M(M)	960	57.5	51.3K	7000[5]	590
19	0608	029	NAVY(M*)	1270	50.3	45.0K	---	Damaged
19	1944	030	M8M(M)	960	42.7	38.8K	6350[5]	480
19	2120	031	NAVY(M*)	1270	39.8	41.3K	5650[5]	367[6]
19	2237	032	NAVY(M*)	127C	43.8	43.1K	5650[5]	370
19	2358	033	M8M(M*)	880	50.2	---	6750[5]	550

[1]All projectiles are Martlet 2C's (in-gun wt 415 lb; flight wt 185 lb) except for (W) wooden slugs (nomiral in-gun wt 415 lb) and (L) Lahive 15° cone (in-gun wt 274 lb).
[2]M-multi-point ignition; M*-multi-point ignition with shear lip on base plate.
[3]S-strain gage (HAT); T-Tourmaline gage; K-Kistler gage.
[4]No vacuum. All other shots had gun barrel evacuated to 0.1 atm.
[5]Velocity estimated from apogee.
[6]Apogee estimated from top of TMA trail.

Table II. Sixteen-Inch Firings at YPG-1966 (Continued)

b) Martlet 2C Dispersion*

Rd No.	Apgoee Kilofeet	Elevation Degrees	Azimuth Degrees	Impact Range Kilofeet
004	415	83.9	77(79.6)	161E(158)
005	398	---	---	---
006	400	83.6	83(84.2)	164E(159)
007	Damaged	---	---	---
008	375	84.0	72	144E
009	410	84.2	72(75.0)	149E(146)
010	310	85.0	74	100E
011	410	85.0	78	129
012	540	85.0	72	167E
014	415	84.2	80	153
015	535	84.5	76	167
016	Damaged	---	---	---
017	369	---	---	---
018	395	84.5	78	137E
019	375	83.5	79	153E
020	415	83.9	76	161E
021	Damaged	---	---	---
022	400	83.9	74	156E
023	410	83.6	76	167E
024	510	84.3	70	182E
025	490	83.6	81	196E
026	530	83.8	77	207E
027	400	83.7	76	162E
028	590	84.8	75	188E
029	Damaged	---	---	---
030	480	83.5	78	198E
031	367	---	78	149
032	370	83.4	79	155
033	550	84.2	74	201E

E - Estimated from first thirty seconds of trajectory.

*Quantities in parentheses were obtained by survey of actual impact points (Figure 10).

Table III. Barbados Gun Performance

a) Single point ignition, 220 M8M

$p > 38{,}000$ psi

Date	Rd[3] No.	Charge Wt.	Pressure kilo lb/in.^{2}		MV	Apogee kilofeet
			M11	Strain Gage		
24 Mar 65	098	750	45.8[1]	45.3	6100R	427
28 Mar 65	104	725	38.8[1]	38.9	5820	389
28 Mar 65	105	730	38.6[1]	37.8	5750	384
11 July 65	125	780	44.8	41.8	6160R	436[2]
12 July 65	126	790	49.3	45.2	6160R	444
12 July 65	127	780	44.1	40.8	6140R	438
17 Nov 65	7	750	40.8	41.0	6000[4]	390
17 Nov 65	8	750	37.9	37.5	5940R	404
17 Nov 65	10	770	41.1	41.4	6120[4]	400
18 Nov 65	11	770	35.0	40.2	5970[4]	408
18 Nov 65	13	750	42.2	42.4	6050R[4]	421
18 Nov 65	14	750	38.0	40.7	5800R	380
21 Nov 65	19	780	39.8	39.0	6130[4]	414

[1] MK 6 gages.

[2] Gun elevation was 82.5°. For all other shots, it was 85°.

[3] If round number has not been assigned, number in series is given.

[4] Bore was evacuated to 0.1 atm.

R-Velocity estimated from radar.

Table III. Barbados Gun Performance (Continued)

b) Single point, spaced charge, 225 WM/M

Date	Rd No.*	Charge Wt.	Pressure kilo lb/in^2 M11	Pressure kilo lb/in^2 Strain Gage	MV	Apogee kilofeet
24 Feb 66	15	850	54.0	46.0	5900R†	395
24 Feb 66	16	850	51.0	---	6080R†	426
24 Feb 66	17	850	48.6	---	5760R	377
28 Sept 66	1	825	53.5	52.3	†	300
28 Sept 66	2	825	53.6	52.4	†	414
28 Sept 66	3	825	49.8	49.4	6200R†	442
29 Sept 66	4	780¶	45.2	---	†	386
29 Sept 66	5	825	47.6	47.0	†	356
29 Sept 66	6	825	48.1	48.5	---	373
29 Sept 66	7	825	55.1	54.3	†	392
29 Sept 66	8	825	55.7	53.4	†	415
29 Sept 66	9	825	46.3	44.6	†	402

*Round number is number in given series.

†Bore was evacuated to 0.1 atm.

R-Velocity was estimated from radar.

¶This round struck 4 inches short of seating position with 100 tons of ram force applied. Charge was, therefore, reduced 45 pounds.

this step was caused by shock waves formed between the end of the powder bags and the pusher plate. Three light wood spacers were inserted to insure that the end powder bag was in contact with the pusher plate and that the free volume was divided into three uniformly spaced thirds. This modification eliminated the step in the pressure curve, but reduced the peak pressure for fixed charge weight by 6-8000 psi. Thus, with a spaced charge an increase in charge weight is required. Since November 1965, all HARP 16-inch guns have used spaced charges.

Table IIIa and particularly Table IIIb show considerable scatter in breech pressures and apogees for the same charge. Part of this is due to variations in required ram pressures, but most of it was believed to be caused by small sabot or projectile damage induced by the single point ignition which can project the end unburnt powder bags at the pusher plate. In August 1966, it was decided to develop a multi-point ignition system to ignite the powder bags simultaneously.

The usual powder charge consists of 100 pound bags with igniter patches filled with black powder sewed to the bottom. Pairs of squibs were sewed to the black powder patches of every other powder bag and wired in parallel to the firing circuit. The bags were then loaded so that each bag without squib had its black powder patch in contact with a patch of a bag with squib. Thus, each bag was in direct contact with two squibs.

This ignition system was first tested at SRI's Highwater Laboratory in the expendable "stub gun" formed from a 20-foot section of 16-inch tube, and then in the 109-foot horizontal fire 16-inch gun. This modification also had the effect of reducing pressure for a fixed charge but more importantly a significant improvement in muzzle velocity seemed to be present. The October Yuma series verified this improvement with a new record apogee of 540,000 feet and a record muzzle velocity of 7100 feet per second. In November, the present record apogee of 590,000 feet (111 miles; 180 km) was established.

Despite the data scatter, the performance improvement of multi-point ignition can be simply summarized. For a breech pressure of 44,000 psi, M8M with single point ignition and evacuated barrel will yield 6250 feet per second and an apogee of 460,000 feet while the addition of multi-point ignition raises these values to 6720 feet per second and 530,000 feet. Similarly, WM/M at a breech pressure of 50,000 psi yields 6200 feet per second and 440,000 feet for single point ignition; and the improved values of 6800 feet per second and 540,000 feet for multi-point ignition.

Early in the HARP program, it was hoped that the large stocks of surplus Navy 16-inch propellant could be used but this powder, designed to launch 2700 pound shells at 2500 feet per second, seemed to be too slow burning for the high performance HARP projectiles. The first wooden slug firings of June used the Navy propellant and breech pressures in excess of 14,000 psi could not be produced. As a final effort to employ this cheap available propellant, it was decided to try multi-point ignition on large charges of the Navy propellant. To speed up its burning characteristics, shear lips were placed on the pusher plates to hold them in place until approximately 3,000 psi was reached. Highwater tests of this were promising and the Yuma firing showed that this could be successfully used to reach 400,000 feet. Since powder costs equal vehicle metal parts costs, for missions requiring moderate altitudes, the use of the Navy propellant halves the shot costs. It is interesting to note that the peak charge weight of 1296 pounds is almost double the service charge weight of 660 pounds and is the largest charge ever used in a 16-inch gun.

3.2 Dispersion

Based on the experience of the Barbados gun, the dispersion of the Yuma gun was estimated to be ±3 miles. On seven occasions, the MPS radar acquired impact data including impact velocities between 3000 and 4000 feet per second. The upleg data of the other shots were used to estimate impact parameters, and the results for all rounds are given in Table IIb. In all cases, the lateral dispersion was less than 3 miles.

Although the nominal elevation for all shots was 85°, the radar trajectories gave an elevation range of $83.6 \rightarrow 84.8$ or an effective elevation of $84.2^\circ \pm 0.6^\circ$. Similarly, an azimuth variation of $72^\circ \rightarrow 83^\circ$ was observed for a nominal azimuth 78.2°. This large variation in azimuth is misleading since the horizontal component of the angle between the initial tangent to the trajectory and the bore line is more appropriate than the angle between the vertical planes containing the initial tangent and the bore line, i.e., the azimuth change. If this component is denoted by J_H, it is approximately given by the relation*

$$J_H = (A_t - A_g) \cos E \qquad (1)$$

where E = the gun elevation

A_t = the azimuth of the trajectory

A_g = the azimuth of the gun.

For the near vertical gun, the best estimate for A_g is the average of the observed A_t's; i.e., 77.5°. According to Equation (1), the maximum value of J_H is $.44^\circ$. Thus, both the vertical and horizontal components of the angular dispersion are about $.5^\circ$ or 9 mils.

In June, the radar impact data was used to actually locate three of the impact points (Figure 10). The high impact velocity shattered the projectiles into small pieces and indicated the need for some type of aerodynamic deceleration device for ground recovery.

An interesting fact came to light during the estimation of impact ranges. For the apogees achieved, the Coriolis acceleration due to the rotation of the earth caused a movement of the impact point of between 11,000 feet and 19,000 feet west of the point computed for a nonrotating coordinate system. This can be seen from the simple formula for Coriolis deflection, X_c.

$$X_c = \frac{8}{3} \omega \sqrt{\frac{2}{g}} (\cos \theta) Z_a^{3/2} \qquad (2)$$

This relation is derived in the Appendix.

Figure 10. Typical depression resulting from impact of Martlet 2C

where ω = .000073 rad/sec (earth's angular velocity)

$\theta = 33^{\circ}$ (latitude)

Z_a = apogee.

3.3 Payload Performance

Of the 29 Martlet 2C's fired, four were damaged, one just reached glow altitude for the TMA (Rd. No. 010) and twenty-four produced excellent trails. The June data have been completely reduced (C-21) and the data from the other two series are under reduction. Samples of the June data are shown in Figures 11 and 12. Since a wind of 100 meters per second is 250 miles per hour in English units, the peak wind speed shown is about 220 miles per hour. The rotating wind vector shown in Figure 12 was observed in over half of the Yuma trails and has been frequently observed from rocket flights at Eglin Air Force Base, Florida and only once in Barbados. The seven trails of the night of 18-19 November are particularly valuable since the ionosonde and spaced receivers had excellent records and significant correlations are believed to be present.*

The Lahive 15° cone had a 250 MHz transmitter with two antennas and several calorimeter sensors. This cone was successfully launched at 7100 feet per second, and TM transmission was received for the entire flight time. Although apparently the leads to the calorimeter sensors were broken, all other components functioned perfectly and this first flight test was considered an engineering success.

4. FIVE-INCH FIRINGS - OCTOBER TO NOVEMBER 1966

The 5-inch gun was installed in October 1966 and participated in the October and November series. Three aluminized parachute ejection flights for winds and two fiberglass nose recovery attempts were made in October, and sixteen aluminized parachute ejection flights were made in November. The results are summarized in Table IV.

**The Naval Electronics Laboratory (D-5) has measured for some time drift of D-layer irregularities over Yuma with a VLF sounder and also has correlated those measurements for this night with the neutral winds.*

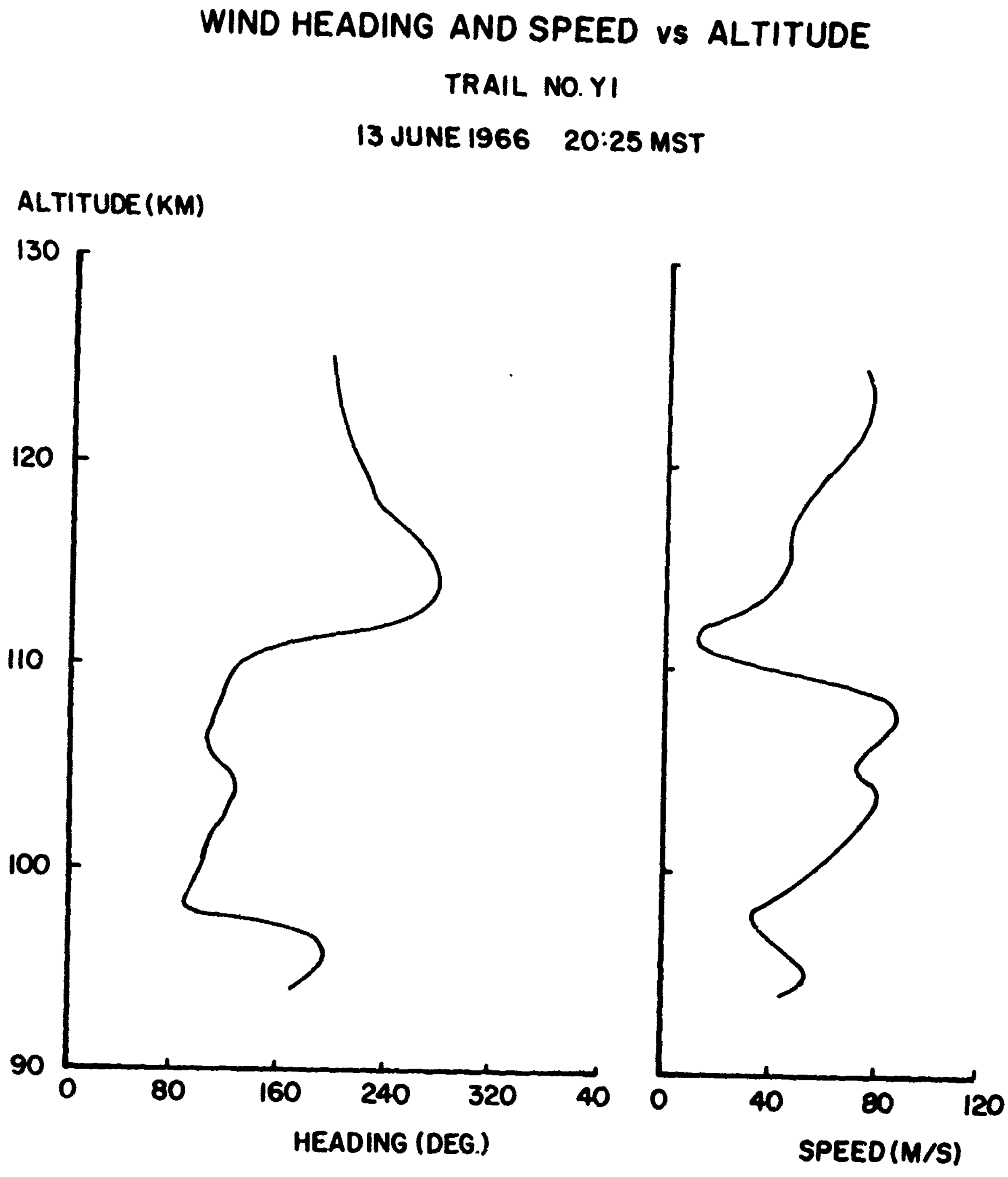


Figure 11. Yuma wind profile Y1

WIND HEADING AND SPEED vs ALTITUDE

TRAIL NO. Y5

15 JUNE 1966 03:05 MST

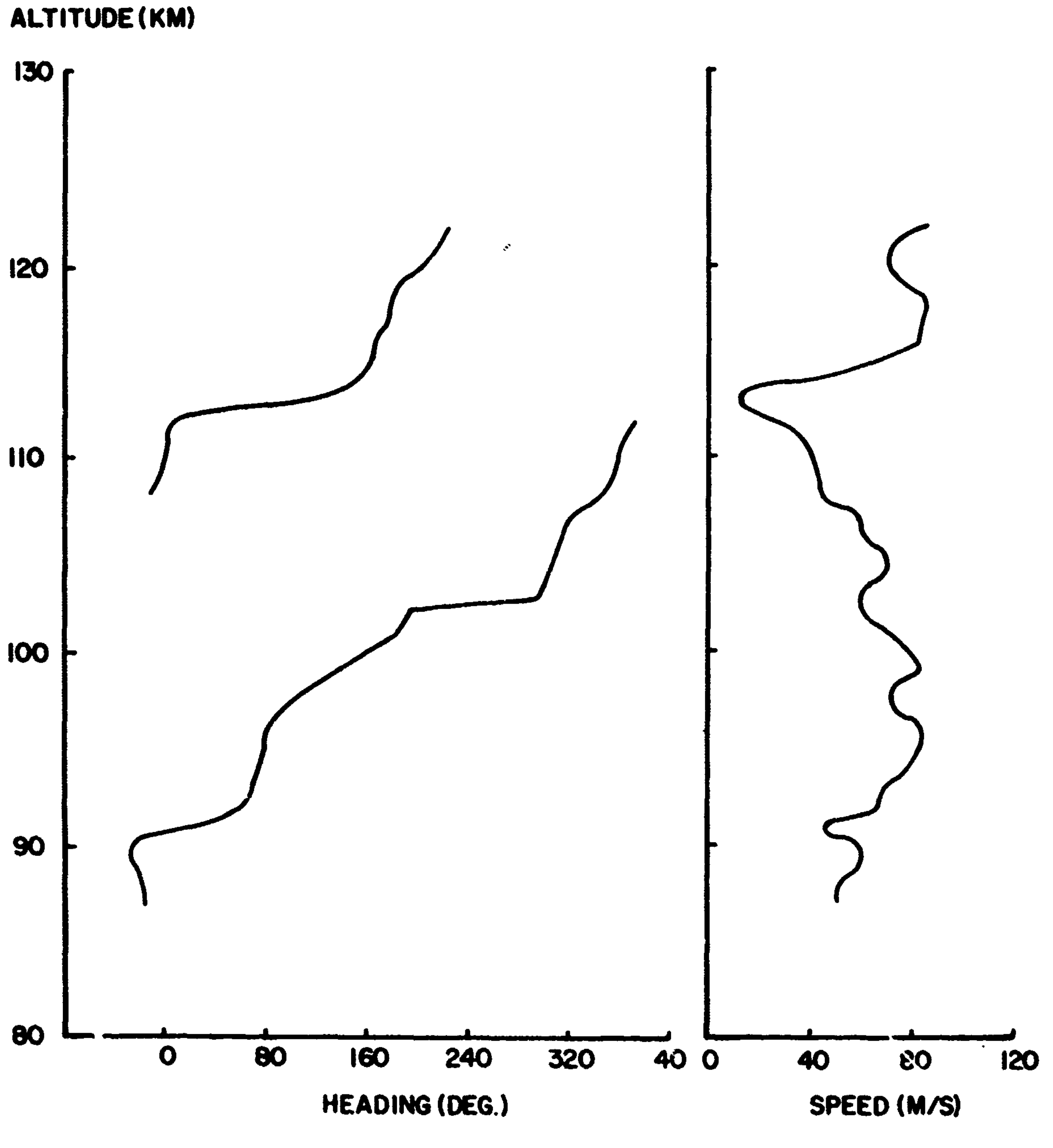


Figure 12. Yuma wind profile Y5

Table IV. Five-Inch Firings at YPG-1966

Date	Time	Rd No.	Elev	Parachute Max. Alt. Kilofeet	Remarks
Oct 14	1603	5001	85	203	
25	1412	5002	85	215	
25	1532	5003	85	157	Early ejection-fiberglass nose (not recovered)
25	2201	5004	85	218	
27	1015	5005	85	155	Early ejection-fiberglass nose (recovered)
Nov 16	1510	5006	87	225	
16	1844	5007	87	210	
16	2044	5008	87	233	
16	2234	5009	87	---	Good flight-no ejection
17	0319	5010	87	220	
17	0410	5011	87	218	
18	1306	5012	87	223	
18	1823	5013	80	172	Low elevation launch
18	2015	5014	88	220	
18	2152	5015	88	224	
18	2345	5016	88	207	
19	0103	5017	88	234	
19	0237	5018	88	---	No track
19	0454	5019	88	---	Good flight-no ejection
19	0611	5020	88	---	Poor flight
19	1947	5021	88	228	

4.1 Wind Measurements

Of the 19 wind measuring flights, possibly two were damaged, two had ejection failures, and fifteen were tracked to yield good wind data between 80,000 and 200,000 feet. The data are being reduced by Texas Western College and will appear in the appropriate Meteorological Rocket Network Data Report.

4.2 Fiberglass Nose Recovery

The primary objective of the 5-inch firings was ground recovery of flight components. An important factor for TM design is an insulator for the antenna. Fiberglass noses have been flown but there was a possibility that they could be damaged by aerodynamic heating. In October, two attempts to recover the fiberglass nose were made by attaching them to the standard 2 meter aluminized parachute and ejecting early at an altitude of 160,000 feet. In both cases, the parachutes were acquired and tracked by the radar. In the first case, the radar discontinued tracking the parachute at 10,000 feet and attempted to track one of the recovery helicopters. The helicopter searched in the area of the last radar observation of the parachute, but did not find it. Apparently, unexpected low altitude winds moved it out of the area of search. In the second case, the parachute was tracked to the ground and was picked up by a helicopter within 10 minutes of the nose cone's landing. An examination of the nose showed some burnt and exposed fibers (Figures 13-14).

5. SUMMARY

The major accomplishments of the YPG HARP guns for 1966 are:

a. Demonstrated operational status for both guns and their supporting instrumentation.

b. The use of multi-point ignition for achieving a record altitude of 111 miles.

c. Twenty-four measurements of ionospheric winds with associated ionosonde records which should increase scientific understanding of Sporadic E phenomena.

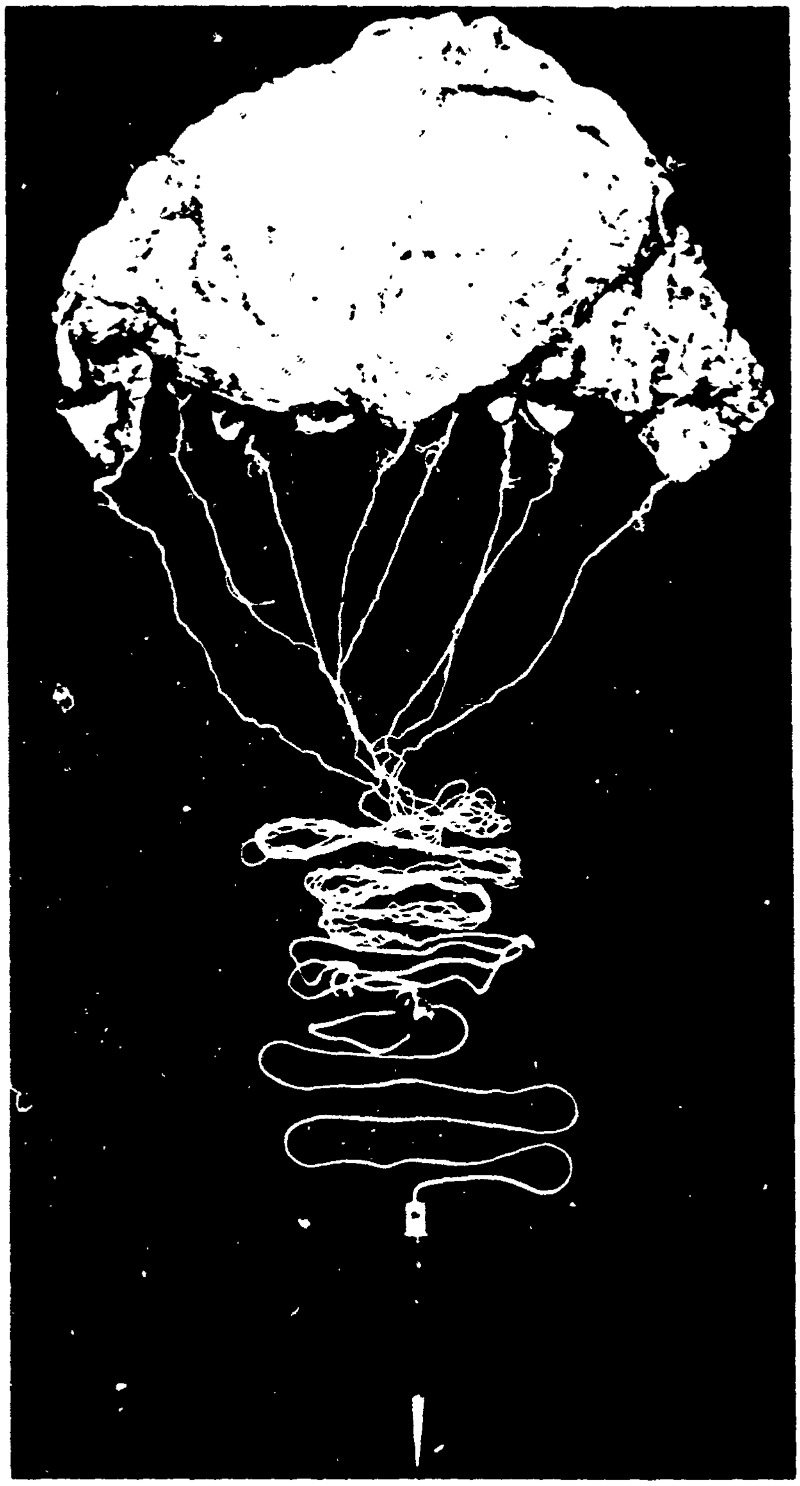


Figure 13. Recovered parachute and nose cone

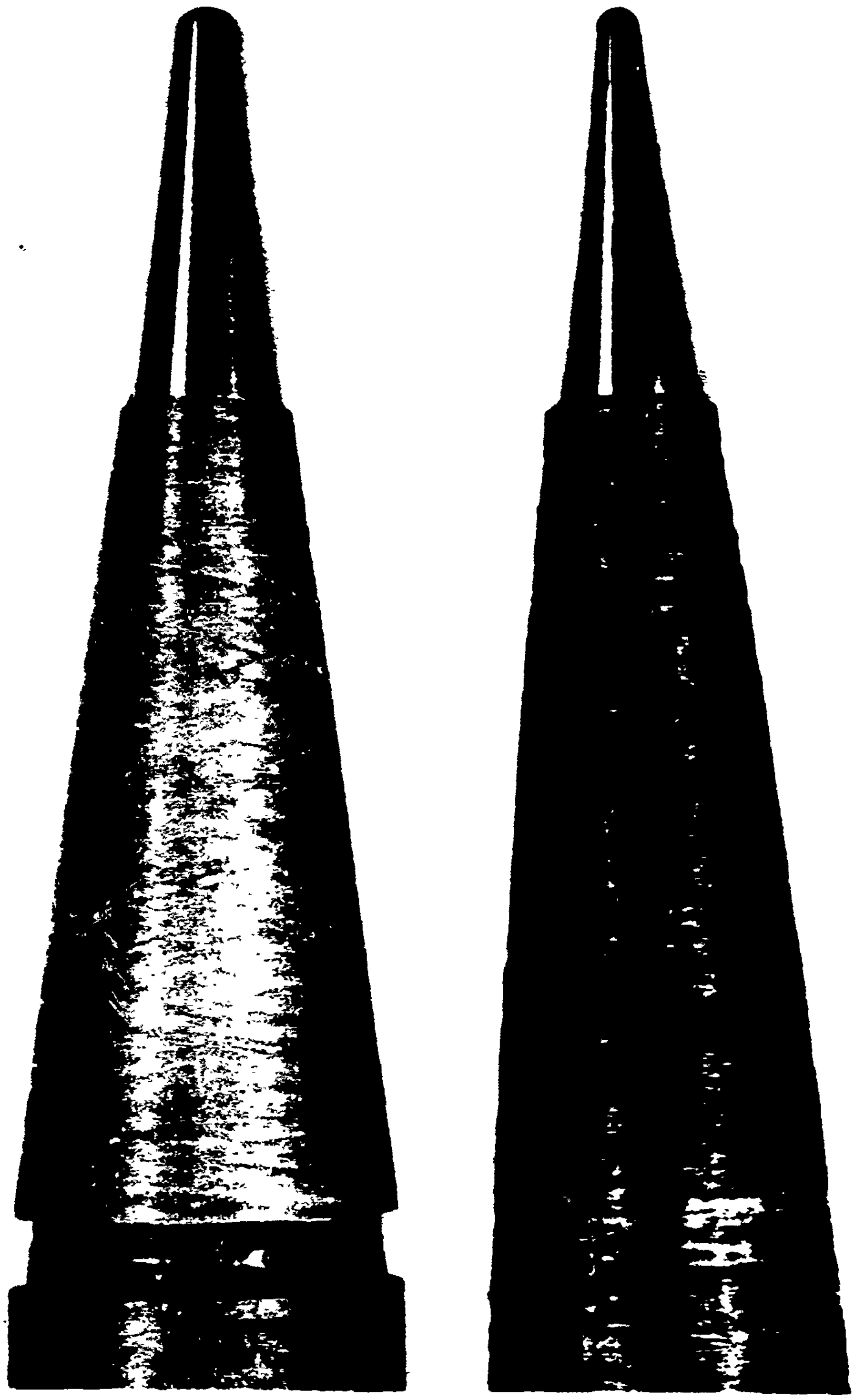


Figure 14. Comparison of fiberglass nose cone before and after gun launch and recovery

d. Operational status for Lahive telemetry which allows that program to move into its aerodynamic measurements phase.

e. Fifteen measurements of stratospheric winds.

f. Demonstrated recovery capabilities for flight components.

BIBLIOGRAPHY

A. HARP Reports Published by BRL

1. Boyer, E. D., "Five-Inch HARP Tests at Wallops Island, September 1963," Ballistic Research Laboratories Memorandum Report No. 1532 (AD 430232) January 1964.

2. Boyer, Eugene D.,"Five-Inch HARP Tests at Barbados, West Indies, January-February 1966," Ballistic Research Laboratories Memorandum Report No. 1771 (AD 640438) July 1966.

3. Boyer, E. D. and MacAllister, L. C., "Seven-Inch HARP Gun Launched Vertical Probe System: Initial Development," Ballistic Research Laboratories Memorandum Report No. 1770 (AD 640825) July 1966.

4. Braun, Walter F., "An Inbore Velocity Measuring Probe System for Large Caliber Guns," Ballistic Research Laboratories Technical Note No. 1610 (AD 637280) April 1966.

5. Brown, J. A. and Marks, S. T., "Feasibility Test of a Potential Meteorological Shell for the Standard 175 Mm Gun," Ballistic Research Laboratories Technical Note No. 1584 (AD 631245) February 1966.

6. Cruickshank, W. J., "High "g" UHF Telemetry for Gun-Launched Sounding Probes," Ballistic Research Laboratories Memorandum Report No. 1632 (AD 463928) January 1965.

7. Cruickshank, W. J., "A Feasibility Test of a 1750 Mc/s Telemetry and Tracking System for Five-Inch HARP Projectiles," Ballistic Research Laboratories Memorandum Report No. 1651 (AD 469653) May 1965.

8. Evans, J. W., "Evaluation of a Tunnel-Diode Oscillator for Use in Gun Probe Telemetry," Ballistic Research Laboratories Memorandum Report No. 1711 (AD 631514) November 1965.

9. Evans, J. W., "Development of Gun Probe Payloads and a 1750 Mc/s Telemetry," Ballistic Research Laboratories Memorandum Report No. 1749 (AD 637747) May 1966.

10. Frankle, J. M., "An Interior Ballistic Study of a 24-Inch Gun for Project HARP," Ballistic Research Laboratories Technical Note No. 1606 (AD 486743) May 1966.

11. MacAllister, L. C. and Bradley, J. W., "Comments on the Use of Guns to Launch High Altitude Probes," Ballistic Research Laboratories Memorandum Report No. 1252 (AD 237038) March 1960.

BIBLIOGRAPHY (Continued)

12. Marks, S. T. and Boyer, E. D. "A Second Test of an Upper Atmosphere Gun Probe System, Ballistic Research Laboratories Memorandum Report No. 1464 (AD 405889) April 1963.

13. Marks, S. T.; MacAllister, L. C.; Gehring, J. W.; Vitagliano, H. D., and Bentley, B. T., "Feasibility Test of an Upper Atmosphere Gun Probe System," Ballistic Research Laboratories Memorandum Report No. 1368 (AD 267345) October 1961.

14. Marks, S. T.; Pilcher, J.O., and Brandon F., "The Development of a High Acceleration Testing Technique for the Electronic Instrumentation of HARP Projectile Systems," Ballistic Research Laboratories Memorandum Report No. 1738 (AD 635782) March 1966.

15. Mermagen, W. H., "High "G" Telemetry for Ballistic Range Instrumentation," Ballistic Research Laboratories Memorandum Report No. 1566 (AD 444246) April 1964.

16. Mermagen, W. H. "Telemetry Experiments Conducted on the HARP Project in British West Indies and Wallops Island, Virginia During the Period Jan-Mar 1964," Ballistic Research Laboratories Memorandum Report No. 1578 (AD 449867) July 1964.

17. Mermagen, W. H., "HARP 250 Mc Telemetry Experiments, Jun-Oct 1964," Ballistic Research Laboratories Memorandum Report No. 1614 (AD 459576) November 1964.

18. Mermagen, W. H., "HARP 250 Mc/s Telemetry Experiments, Wallops Island, March 1965," Ballistic Research Laboratories Memorandum Report No. 1694 (AD 631268) September 1965.

19. Mermagen, W. H.; Cruickshank, W. J., and Vrataric, F., "VHF and UHF High-G Telemetry Instrumentation for HARP Vehicles," Ballistic Research Laboratories Memorandum Report No. 1768 (AD 640596) May 1966.

20. Murphy, C. H.; Bull, Gerald V., and Edwards H. D.,"Upper Atmosphere Winds Measured by Gun-Launched Projectiles," Ballistic Research Laboratories Memorandum Report No. 1747 (AD 637850) May 1966.

21. Murphy C. H., and Bull, G. V., "Review of the High Altitude Research Program (HARP)," Ballistic Research Laboratories Report No. 1327 (AD 645284) July 1966.

BIBLIOGRAPHY (Continued)

B. Partial List of HARP-SRI Reports

1. Bull, G. V., Lyster, D., and Parkinson, G. V., "Orbital and High Altitude Probing Potential of Gun-Launched Rockets," SRI-H-R-13, October 1966.

2. Eyre, F. W., "The Martlet 2A Ballistic Vehicle-Summarized Performance Data," TN 64-4, May 1964.

3. Eyre, F. W., "Ballistic Development Testing of M8-M Propellant in the 16" Barbados Gun," SRI-H-R-1, November 1964.

4. Groundwater, F. M., "Report on Martlet 3B Series of Firings," SRI-H-R-7, September 1964.

5. Luckert, H. J., "Report of the March 1965 Test Firing Series Project HARP," SRI-H-R-9, July 1965.

6. Luckert, H. J., "Report of the May/June 1965 Test Firing Series Project HARP," SRI-H-R-10, September 1966.

7. McKee, R. M., "A Parametic Study of Multi-Stage Gun Launched Rockets," SRI-H-R-2, March 1965.

8. McKee, R. M., "Continuation of Gun-Launched Rocket Parametric Study," SRI-H-R-5, May 1965.

9. Parkinson, G. V., "Simple Internal Ballistics Theory for Single and Double Chamber Guns," SRI-H-TN-4, August 1966.

10. Staff, Dept. of Mechanical Engineering, "Project HARP-Description and Status," Report 62-5, 1962.

11. Staff, Dept. of Mechanical Engineering, "Project HARP-McGill University, Report on the First Twelve Firings and Status as of July 30, 1963," Report 63-5, November 1963.

12. Staff, SRI, "Report on the December 1964 Test Firing Series," SRI-H-R-3, April 1965.

C. HARP-Other Publications

1. Black, A. V.; Kodis, A. L., and Smith, L. C., "High Altitude Gun Probes (Development of Langmuir Probes) Final Report," G.C.A.T.R. 65-15-G, September 1965.

2. Brown, J. A., and Marks, S. T., "High Altitude Gun Probe Systems for Meteorological Measurements," The Meteorological Rocket Network, IRIG Document 111-64, pages 211-221, February 1965.

BIBLIOGRAPHY (Continued)

3. Fuller, R. N., "Upper Atmosphere Winds from Gun Launched Probes (Barbados July 1964-August 1965)," Ballistic Research Laboratories Contract 169, Report 1.

4. Fuller, R. N., "Upper Atmosphere Winds from Gun Launched Vertical Probes (Barbados 20-23 September 1965)," Ballistic Research Laboratories Contract 169, Report 2.

5. Fuller, R. N., "Upper Atmosphere Winds from Gun Launched Vertical Probes (Barbados 16-23 November 1965)," Ballistic Research Laboratories Contract 169, Report 3.

6. Fuller, R. N., "Upper Atmosphere Winds from Gun Launched Vertical Probes (Yuma, 13-15 June 1966)," Ballistic Research Laboratories Contract 169, Report 4.

7. "Investigation of the Effect of Ram Force on Breech Pressure and Muzzle Velocity in the 16.5" Smoothbore Gun," Inspection Services Canadian DND, TN 4/65, February 1965.

8. Lorimor, George, "Analysis of Carriages Suitable for 7-inch HARP Gun," Rock Island Arsenal Report 3-65, January 1965.

9. Lorimor, George, "7-inch HARP Final Report," Rock Island Arsenal Technical Report 66-3411, November 1966.

10. McCluney, Eugene L., "Theoretical Trajectory Performance of 5" Gun Probe System," ECOM 5015, ERDA, WSMR, October 1965.

11. Mermagen, W. H.; Cruickshank, W. J., and Vrataric F., "VHF and UHF High-G Telemetry for HARP Vehicles," AGARD CP 10, September 1966.

12. Murphy, C. H., and Bull, G. V., "Review of the High Altitude Research Program," AGARD CP 10, September 1966.

13. Northcote, D. L. S., "Harp 1/4 Scale Models General Description of Instrumentation," Inspection Services Canadian DND TN 5/64, December 1964.

14. Perrine, R. H., "HARP 7-15 June 1966, Firing Report 6147," Yuma Proving Ground, Arizona, October 1966.

15. Rossmiller, R., and Salsbury, M., "16-inch HARP Work at Rock Island Arsenal-Summary Report," Rock Island Arsenal Technical Report 66-1493, April 1966.

16. Spalinger, R. E., "Sound and Pressure Level Measurements of the HARP-Barbados 16.5-inch Gun with a 51 ft. Muzzle Extension," Eglin Air Force Base, APGC-TR-65-50, July 1965.

17. Wasserman, S.; Lattal, G., and Smolnik, J., "Parametric Studies on Use of Boosted Artillery Projectiles for High Altitude Research Probes, Project HARP," Picatinny Arsenal Technical Report No. 3147, January 1964.

18. Wasserman, S; Bull, G. V., and Murphy, C. H., "Rocket Assist Projectiles for High Altitude Research Probes (Project HARP)," Bulletin of the 20th Interagency Solid Propulsion Meeting-July 1964, Vol. IV, Chemical Propulsion Information Agency Publication No. 49B, pages 371-382, October 1964.

19. White, C. E., "Sound Pressure Level Measurements of the HARP 16.5" Smoothbore Gun at Barbados during the Firings in Dec 1964," Inspection Services, Canadian Department of National Defence, TN 1/65, January 1965.

20. Williamson, L. E., "Gun-Launched Vertical Probes at White Sands Missile Range," Atmospheric Sciences Office, ECOM-5030, (AD 482330) February 1966.

21. Wilkin, N. D., "TM Research Program - High-g Tests of Components," HDL TM-65-33, July 1965.

D. HARP-Scientific Publications*

1. Bull, G. V., and Murphy, C. H., "Gun Launched Missiles for Upper Atmosphere Research," AIAA Preprint 64-18, January 1964.

2. Bull, G. V., "Development of Gun Launched Vertical Probes for Upper Atmosphere Studies," Can. Aero & Space Jrl., Vol 10, pages 236-247, October 1964.

3. Bull, G. V., and Murphy, C. H., "Gun Boosted Rockets for High Performance Sounding Missions," AIAA Sounding Rocket Vehicle Technology Specialist Conference Proceedings, February 1967.

4. Eyre, F. W., "The Development of Large Bore Gun Launched Rockets," Can. Aero. & Space Jrl., Vol. 12, pages 143-149, April 1966.

---

* *Non-HARP sponsored publication of interest is: Valenti, A. M.; Molder, S., and Salter, G. R., "Gun Launching Supersonic Combustion Ramjets," Astronautics and Aerospace Engineering, December 1963.*

5. Gossard, Earl, "The Apparent Movement of the Spectral Components in Fading Records of Ionospherically Reflected Radio Waves," Jour. Geo. Research, Vol. 72, pages 1563-1570, March 1967.

6. Millman, P. M., "Big Gun on Barbados," Sky and Telescope, Vol. 32, pages 64-67, August 1966.

7. Murphy, C. H.; Bull, G. V., and Edwards, H. D., "Ionospheric Winds Measured by Gun Launched Projectiles," Jrl, Geo. Res. 71, pages 4535-4545, October 1966.

8. Murphy, C. H., and Bull, G. V., "A Review of Project HARP," Planetology and Space Mission Planning, Annals of the New York Academy of Sciences, Vol. 140, Art. 4, pages 337-357, December 1966.

9. Murphy, C. H., and Bull, G. V., "Aerospace Application of Gun Launched Projectiles and Rockets," American Astronautical Society Paper 67-38, March 1967. (See also SRI-TL-1).

10. Raymond, H. A., "Orbit Injection Control for HARP," Can. Aero. & Space Jrl. Vol. 11, pages 154-159, May 1965.

11. Williamson, Edwin L., and Boyer, E. D., "The Gun Launched Meteorological Sounding System," AMS/AIAA Paper 66-382, March 1966.

12. Wright, J. W., and Fedor, L. S., "Comparison of Ionospheric Drift Velocities by Spaced Receiver Technique with Neutral Winds From Luminous Rocket Trails," Space Research VII, North-Holland Publishing Company, Amsterdam, pages 67-72, 1966.

13. Wright, J. W.; Murphy, C. H., and Bull, G. V., "Profiles of Winds in the Lower Thermosphere by the Gun-Launched Probe Technique and Their Relation to Ionospheric Sporadic E," Space Research VII, North-Holland Publishing Company, Amsterdam, pages 113-122, 1966.

14. Wright, J. W.; Murphy, C. H., and Bull, G. V., "Sporadic E and the Wind Structure of the E Region," Jrl. Geo. Res. Vol. 62, pages 1443-1460, 1 March 1967.

APPENDIX

ANGULAR DISPERSION OF GUN LAUNCHED PROJECTILES

Although the simple model of missile motion assumes that the initial direction of the trajectory is that of the gun barrel, and that dispersion is due to variations in muzzle velocity and various aerodynamic effects, this is not the case. Various disturbances at the gun (blast, muzzle whip, sabot separation) can impart linear and angular momentum to the missile. The linear momentum causes the projectile to leave the gun muzzle region in a direction which differs from that of the gun barrel while the angular momentum induces an angular motion which damps out for a stable missile. This angular motion in conjunction with the lift force causes an oscillatory motion in the trajectory so that the direction of the initial tangent and average trajectory direction can also differ (aerodynamic jump). The total angle between the gun barrel and the average trajectory is called the jump angle. This angle is usually less than 5° and can, therefore, be described by two rotations.

If we select Cartesian coordinates so that the Z-axis is vertical, and the X-axis points north in the horizontal plane, the gun barrel direction can be specified by the unit vector.

$$\vec{u}_g = (\cos A_g \cos E_g, - \sin A_g \cos E_g, \sin E_g) \qquad (A1)$$

where A_g is gun asimuth
E_g is gun elevation.

Similarly, the initial direction of the effective trajectory has the direction specified by the unit vector

$$\vec{u}_t = (\cos A_t \cos E_t, - \sin A_t \cos E_t, \sin E_t) \qquad (A2)$$

These vectors can be represented as points on a unit sphere whose latitudes are E_g or E_t and whose longitudes are A_g or A_t. The jump angle is the angle between these vectors. For small changes in elevation angle, Unclassified

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13. ABSTRACT

The 5- and 16-inch guns at Yuma Proving Ground and their associated instrumentation and flight results for 1966 are described in detail. The introduction of multi-point ignition for the 16-inch gun produced a record altitude of 111 miles using special propellants and the moderate altitude of 77 miles with surplus Naval propellant. Twenty-four ionospheric wind profiles have been obtained from 16-inch gun firings and 15 stratospheric profiles from the 5-inch firings. Telemetry performance and ground recovery capability have been demonstrated.

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this angle can be represented by two rotations of radius vector, i.e., a rotation at constant elevation angle and a rotation changing elevation angle. The angular magnitude of these rotations is defined to be J_H and J_V respectively. These angles are simply the length of arc along the circles of latitude and longitude passing through the endpoints of $\vec{u}_g$ and $\vec{u}_t$.

$$J_H \doteq (A_t - A_g) \cos E_g \doteq (A_t - A_g) \cos E_t \tag{A3}$$

$$J_V = E_t - E_g \tag{A4}$$

Since $\cos E_g \doteq \cos 85^\circ = .09$

$$J_H = (.09)(A_t - A_g). \tag{A5}$$

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
HARP						
Gun Launched Projectiles						
Ionospheric Soundings						
Meteorological Soundings						
Aerodynamic Tests						
Materials Testing						